Serial EEPROM Endurance

Welcome to this web seminar on serial EEPROM endurance. My name is Barry Blixt, marketing manager for Microchip's memory division.

Our customers use serial EEPROMs, or E2s, for many different reasons: they are cost effective; they are small with low pincounts; and they use very little power. One of the more interesting features of an EEPROM is its ability to be written, erased, and re-written millions of times. This feature, called endurance, makes E2s very attractive for non-volatile memory applications, like metering and data logging, that need many data changes.

Topics

1. **Defining terms**
2. **Ways to improve endurance**
3. **Microchip's *Total Endurance*^{TM} model**
4. **Actual endurance data**

We want you to understand Endurance so you can make good design choices…

This web seminar has 4 topics:

First, we will define some important terms regarding endurance. We'll also talk about the limitations of data sheet definitions.

The second part of this web seminar will describe how designers can maximize EEPROM endurance in actual applications. This will include a description of how EEPROMs work and their typical failure mechanisms. A key point of this section is that endurance is very dependent on operating conditions.

The third topic is an example problem using Microchip's Total Endurance^{TM} tool, a software model that calculates expected failure rates of Microchip EEPROMs given specific operating conditions. This tool is available for free on our web site.

For the 4th and final topic, I will share with you the results of some actual endurance testing we performed on several manufacturers' EEPROMs.

The overall purpose of this seminar is to give you a good understanding of endurance so that you can make good design choices.

Endurance:

- **Erase/write cycles before failure**

Let's define some terms: Endurance is defined as the number of times that a memory device can be written and re-written before it fails to read back the proper data.

Endurance:

- **<u>Erase/write cycles</u> before failure**

Each programming cycle is usually referred to as an <u>erase/write cycle</u>, since virtually all EEPROMs include an automatic erase step before programming. Since E2s can be programmed down to the byte level, an erase/write cycle could be for as little as one byte to as much as a full page. We will see later how these different write modes have an effect on endurance.

Endurance:

- **Erase/write cycles before failure**

Failures occur because an EEPROM cell can wear out – but, this takes a long time, typically millions of cycles. Once even a single bit can no longer be reliably programmed, the entire device is defined to have failed.

Endurance:

- **Erase/write cycles before failure**

Data Sheet
- **1 M cycles, 25ºC**
- **Limited usefulness**

EEPROM Endurance   Slide 6

Another issue that needs some definition is how endurance is specified on data sheets. Microchip, as well as most other manufacturers, specifies endurance on its data sheets as 1 million erase/write cycles at 25 degrees C.

But what about endurance at other temperatures? What about 2 million or 3 million cycles? Can a designer expect zero fails before 1 million cycles, *or just a small number? Do parts built by different manufacturers have similar endurance characteristics?* Just using the data sheet does not give an engineer sufficient information to answer these questions.

That's why we created the Total Endurance™ modeling software. The model calculates results based on the actual operating conditions that can have a major effect on endurance. The software also allows designers to create what-if scenarios to help in decision making.

With that, let's look at how EEPROMs work and what causes them to fail.

EEPROM Cell Structure

Control Gate
(Row)

Floating Gate

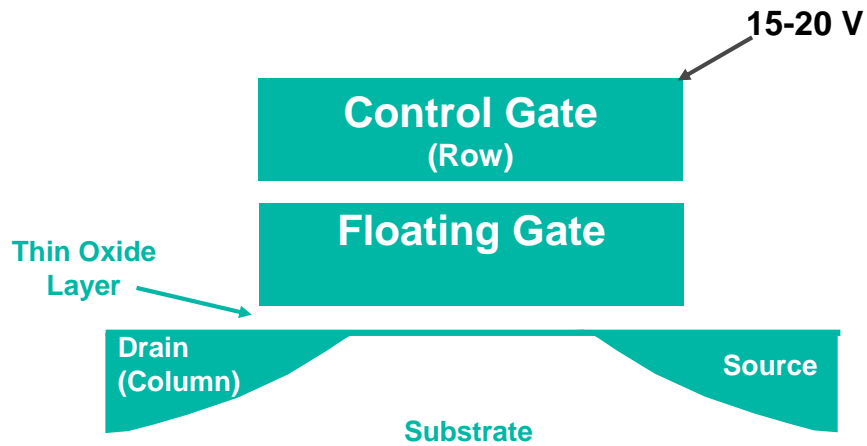**Drain**
(Column)

Source

Substrate
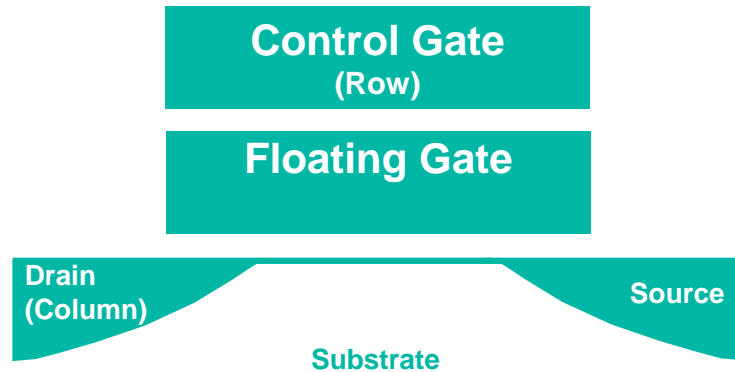
A typical EEPROM cell contains 2 transistors, or gates. of how an EEPROM cell works, we can look at ways that a designer can get more cycles out of a device in a particular application.
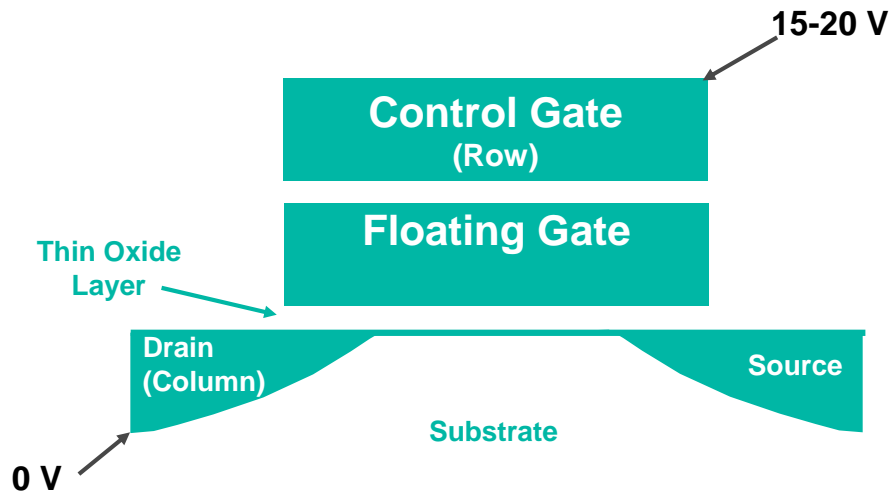
EEPROM Cell Structure

Control Gate
(Row)

Floating Gate

Thin Oxide
Layer

Drain
(Column)

Source

Substrate
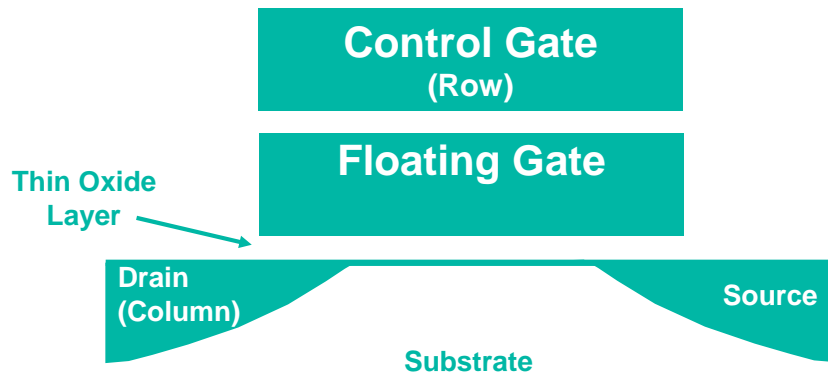
The floating gate is electrically isolated from the rest of the cell by a thin oxide layer.

EEPROM Cell Structure

15-20 V

Control Gate
(Row)
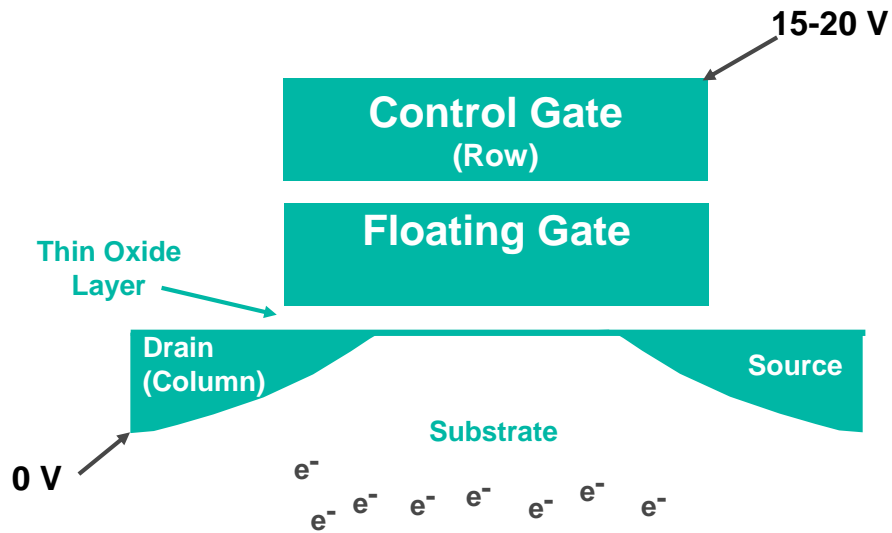
Floating Gate

Thin Oxide Layer

Drain
(Column)

Source

Substrate

To program the cell, a voltage differential is applied. A charge pump increases the 1.8 to 5.5 volt supply voltage up to 15 to 20 volts.
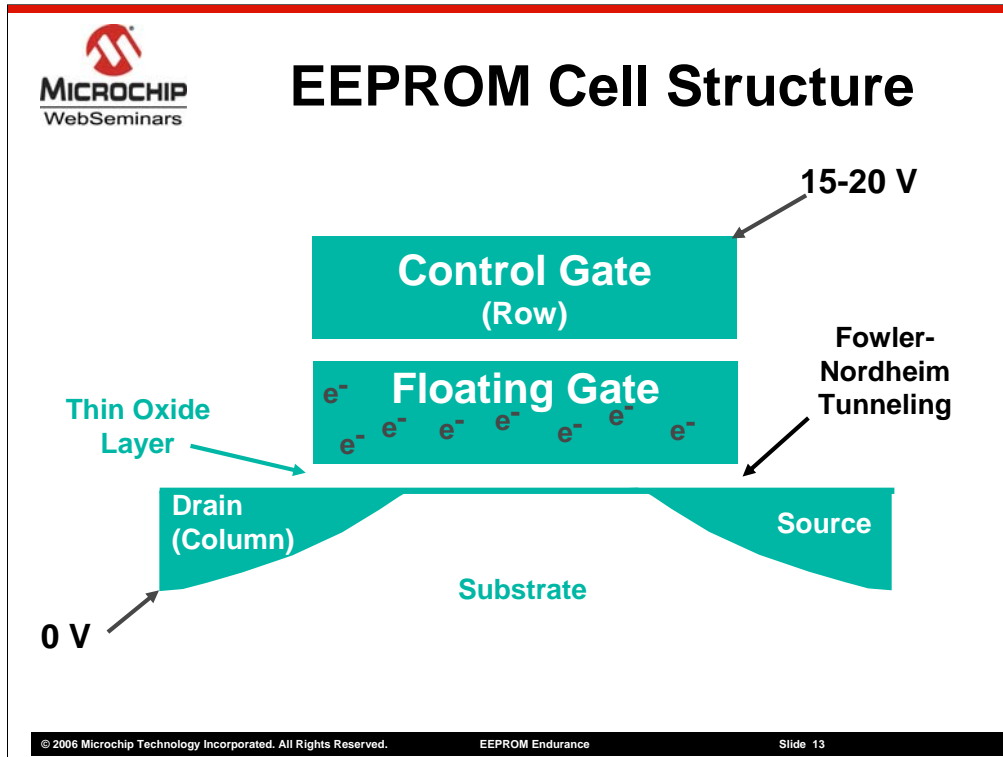
If this <u>high voltage</u> is applied to the control gate, and the <u>drain is connected</u> to ground,

electrons will move from the substrate, though the thin oxide layer, and onto the floating gate, giving it a negative charge.

EEPROM Cell Structure

15-20 V

Control Gate
(Row)

Fowler-
Nordheim
Tunneling

Floating Gate

Thin Oxide
Layer

e⁻ e⁻ e⁻ e⁻ e⁻ e⁻ e⁻ e⁻
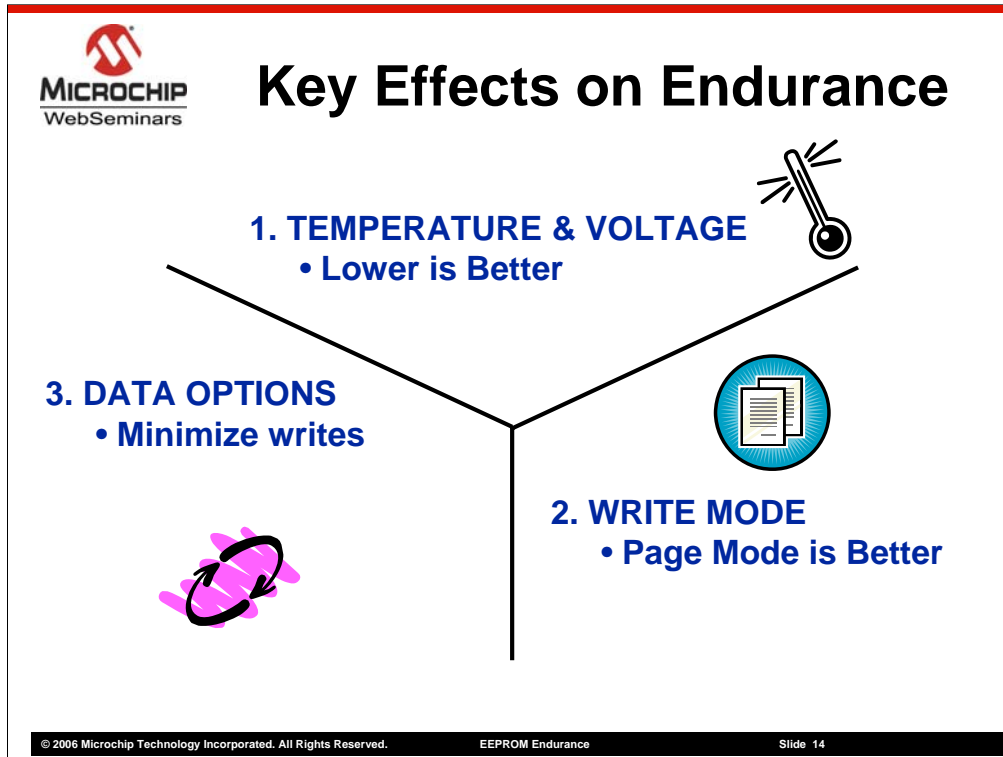
Drain
(Column)

Source

Substrate

0 V

This is a quantum-mechanical process known as Fowler-Nordheim tunneling. The key to this tunneling is that the electrons barely disturb the oxide layer, so the process can be repeated millions of times. A flash cell uses a different programming technique, called Channel Hot Electron Programming, that damages the oxide layer with every write. That's why E2's have much higher endurance than flash, which is usually specified to only 10,000 cycles.

Reversing the voltage differential causes negatively-charged electrons to leave the floating gate and move back into the substrate, leaving the gate with a lack of electrons and a positive charge. This charge on the floating gate determines if the cell, or bit, is a 1 or a zero. If the voltage differential is removed, the electrons stay where they are. Since the floating gate keeps its positive or negative charge when the power is turned off, the EEPROM is non-volatile.

An EEPROM cell fails when the built-in sensing circuitry can no longer determine the charge on the floating gate. After many erase/write cycles, field stresses and the constant tunneling through the thin oxide layer begin to reduce the voltage differential. Also, the thin oxide can begin to leak charge from the floating gate, so the cell is no longer non-volatile. In any of these failure modes, a sense amp can no longer tell the difference between a 1 or a zero.

So, obviously an important part of endurance is the intrinsic structure of the cell. Microchip's EEPROM cell was designed to maximize the amount of endurance available.

But it's not all about the cell structure. Now that we understand the mechanics of how an EEPROM cell works, we can look at ways that a designer can get more cycles out of a device in a particular application.

Key Effects on Endurance

1. TEMPERATURE & VOLTAGE
• Lower is Better

3. DATA OPTIONS
• Minimize writes

2. WRITE MODE
• Page Mode is Better

There are 3 major effects on endurance that designers need to be aware of.

The first is the operating conditions of the application. Our research has shown that higher temperatures and voltages cause faster wear out of the cell. To maximize endurance, designers should choose the lowest operating temperature and voltage possible.

The second key effect on endurance is the choice of write mode. When a single byte is programmed, the energy from the charge pump is concentrated on that one byte. If a page write is used, that energy is dissipated over more bytes, so cell wear is decreased. Microchip builds in circuitry to minimize the wear effect of byte writes, but overall, designers should use Page mode whenever possible.

The third endurance effect is the designer's choice of how often he programs the data. Writing as infrequently as possible will lengthen the device's life.
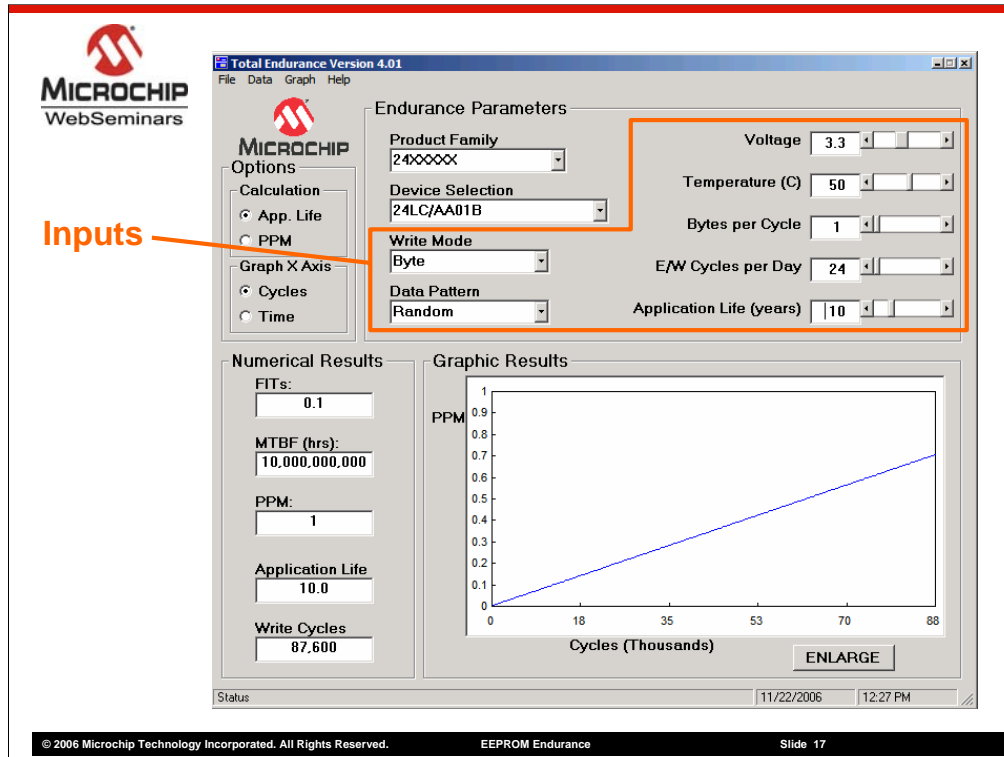
We'll see the effects of changing these parameters in the example of our modeling software. Let's look at the model now.
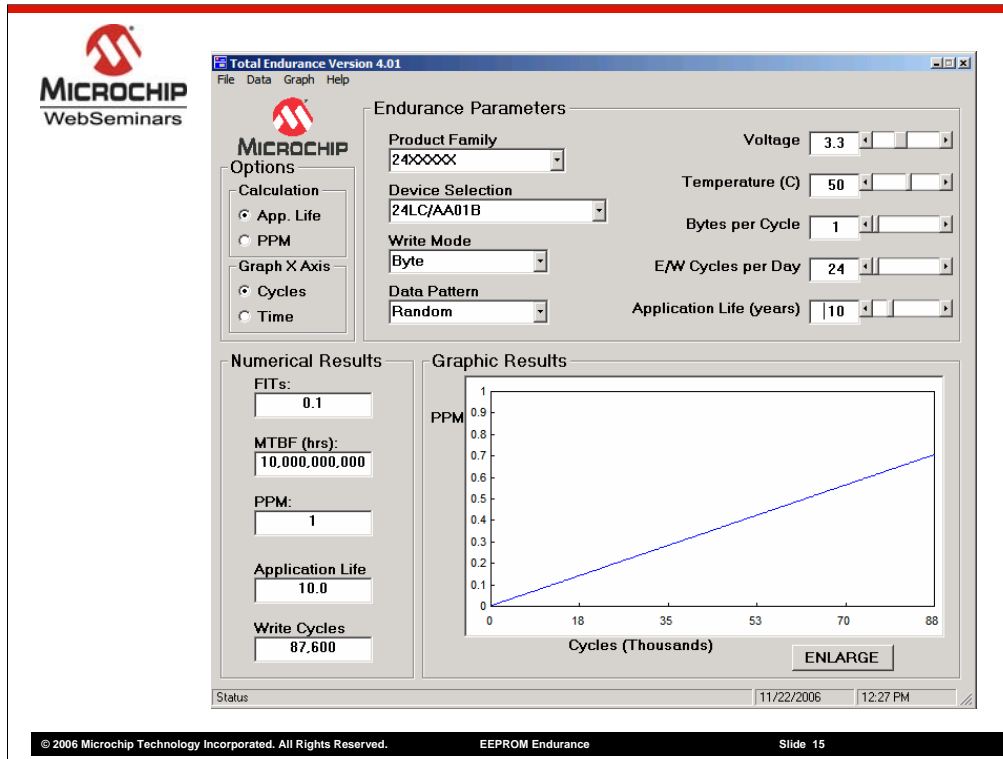
Here is a screen shot of the Total Endurance™ interface.
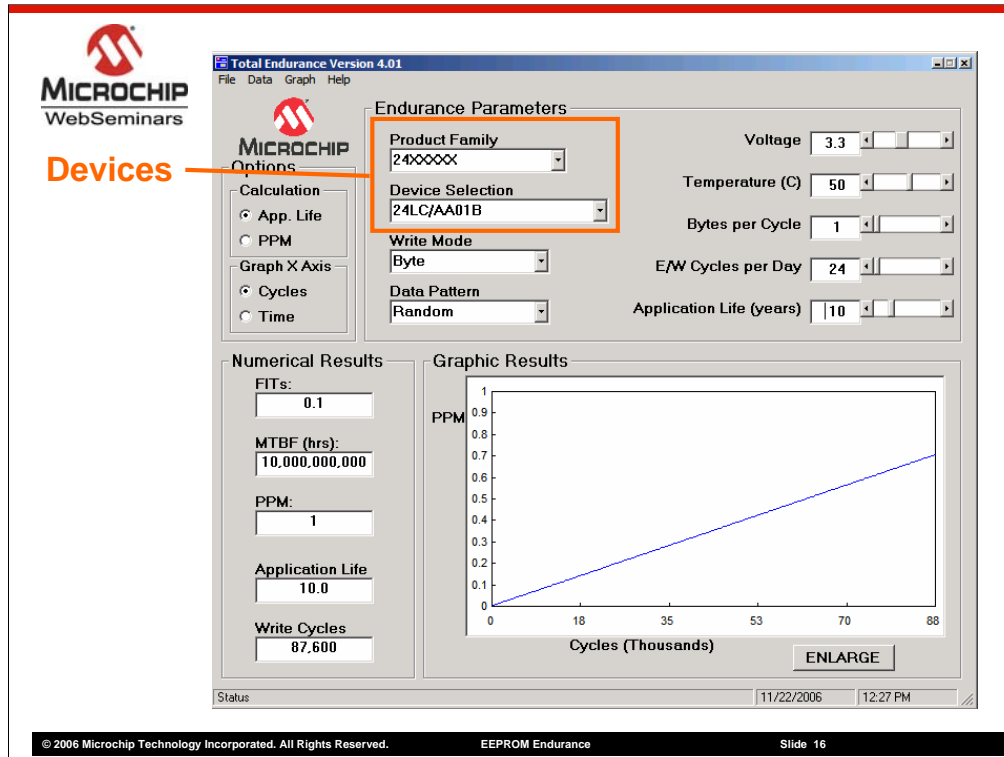
First, you can pick the Microchip device that you want to model. All Microchip memory devices are included, and we add new devices when they are released.

Next, you can enter your application's actual operating conditions. Since endurance is impacted by voltage, temperature, and how the part is programmed, this input section is really the key to the whole model. It is very easy to change a parameter.
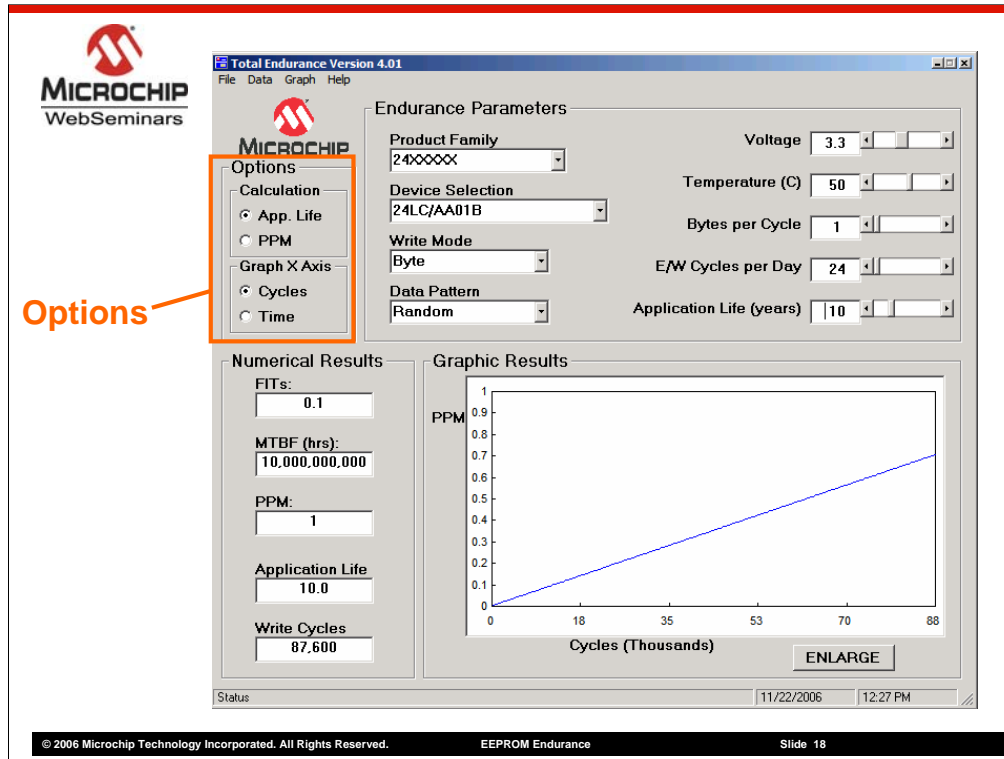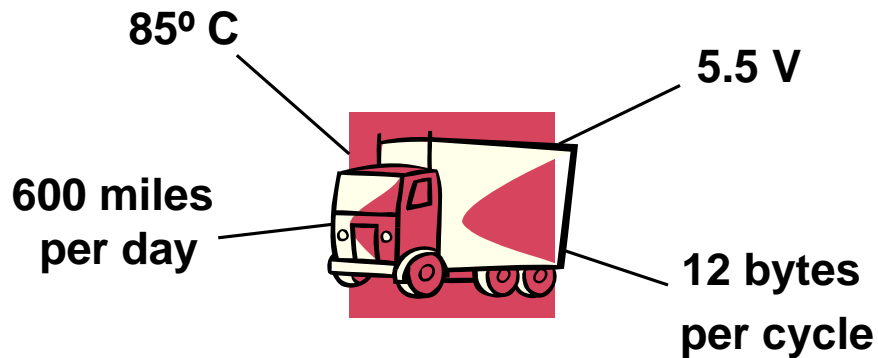
The options section, shown here, lets you select how you want to see the results.
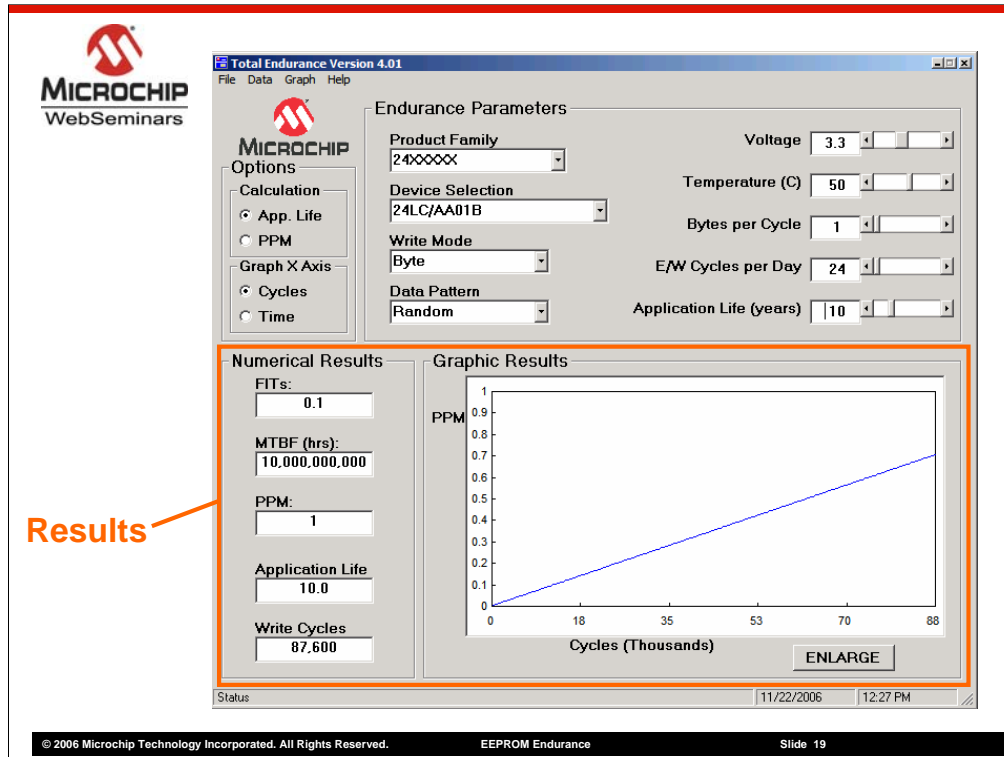
Finally, the <u>results section</u> shows endurance data in both numerical and graphical format. *This data can be exported to spreadsheet or presentation software.*

Now, let's look at an example problem.

Truck Odometer Example:

85º C

5.5 V

600 miles per day

12 bytes per cycle

Goal: <5 ppm, 15 years

Assume we are designing a truck odometer. The odometer has an electronic logbook that is updated every mile so that transportation billing can be accurately measured.

The odometer is mounted in the engine compartment where temperatures can reach 85 degrees C. The truck's electronics operate at 5.5 volts. Twelve bytes of data are written to the EEPROM every mile, and the truck can travel up to 600 miles in a day. Our goal in this example is to have the E2 last for 15 years with fewer than 5 parts per million, or ppm, fails.

A little math tells us that the device will be expected to handle over 3 million erase/write cycles in its 15-year life.

The datasheet only tells us that we can expect to see 1 million cycles at 25C. Let's see how the Total Endurance™ model can give us more specific information.
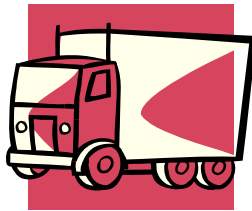
Truck Odometer Options:

Goal: <5 ppm, 15 years

Option 1: 11 ppm, 15 years
Option 2: 5 ppm, 8 years
Option 3: 5 ppm, 15 years (300 cycles)

Here is a summary of the options that we just found from the Total Endurance™ model. These all assume that the odometer has been moved from the hot engine compartment into the cooler truck cab. The goal was to see less than 5 ppm fails after 15 years.

The first option gave us 11 ppm after 15 years of service. Option 2 was 5 ppm after 8 years. The final option was to lower the total number of writes, and the unit will last for 15 years with only 5 ppm fails.

With the help of the model, we quickly found a way to improve the design to an acceptable risk level. Now we can make an informed decision about how long to warranty the product.

www.microchip.com

We have more information on EEPROMs and endurance on our web site.

www.microchip.com

- **Download Total Endurance^{TM} model**
  - → **Search "Total Endurance"**

I encourage you to <u>download</u> the Total Endurance^{TM} software. It's free, and easy to access. Just go to www.microchip.com and search for "total endurance."

Once you've downloaded the model, check out both the FAQs and the Tutorial that are available in the Help menus. There is a more detailed discussion about common endurance misconceptions, cell design, failure mechanisms, and how our engineers developed the model.

www.microchip.com

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WebSeminars

- **Download Total Endurance^{TM} model**
  - → **Search "Total Endurance"**
- **More information on Endurance**
  1. **AN 1019**: Endurance Tutorial
  2. **AN 562**: Using Total Endurance S/W

We have two excellent app notes about endurance on our web site. The first – AN 1019 – describes endurance in more detail. The second – AN 562 – has more hints about how to use the Total Endurance tool.

www.microchip.com

- **Download Total Endurance™ model**
  - → **Search "Total Endurance"**
- **More information on Endurance**
  1. **AN 1019:** Endurance Tutorial
  2. **AN 562:** Using Total Endurance S/W
- **Other memory web seminars**

We also have two other <u>web seminars</u> on serial E2s: an introduction to serial EEPROMs and an introduction to our SEEVAL® 32 developers kit.

www.microchip.com

- **Download Total Endurance^{TM} model**
  - → **Search "Total Endurance"**
- **More information on Endurance**
  1. **AN 1019: Endurance Tutorial**
  2. **AN 562: Using Total Endurance S/W**
- **Other memory web seminars**

- **One more thing…**

One last issue: I mentioned that the Total Endurance model is only good for Microchip devices. Next, I want to address one more question: are all suppliers' EEPROMs the same?

Endurance Test Results:
3 Manufacturers
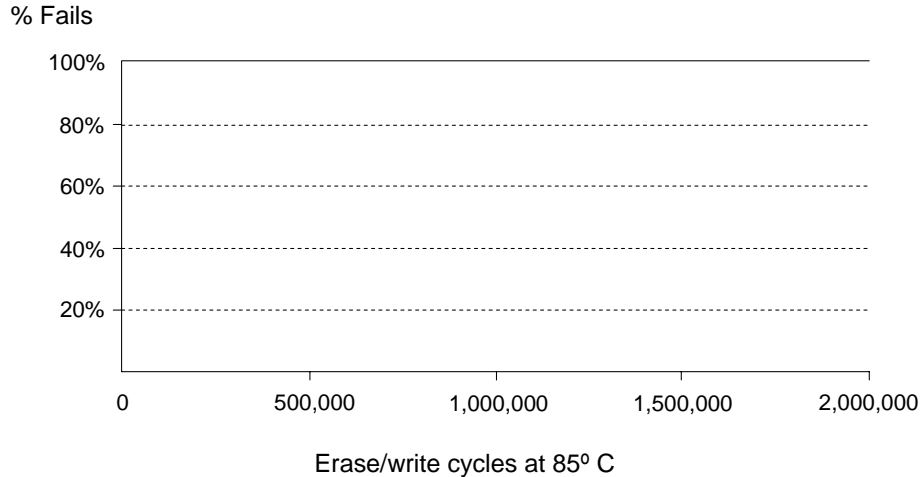
% Fails

100%
80%
60%
40%
20%

0   500,000   1,000,000   1,500,000   2,000,000

Erase/write cycles at 85º C

You now know enough about endurance to predict that EEPROMs from different suppliers, and, therefore, from different manufacturing processes, will have very different endurance characteristics. To confirm that theory, Microchip recently performed some actual, destructive endurance testing on several different manufacturers' devices, including our own. I'll show you the results from 3 manufacturers on this slide. In all cases, the device's data sheet specified 1 million erase/write cycles.

First a word on the test methodology. We purchased all competitors' parts through commercial web sites; we ordered standard Microchip parts from our own sample center. We tested 128 EEPROMs from each manufacturer, each a 16-kbit, I²C™ device. The parts were cycled 2 million times using a random data pattern. We cycled at a high temperature – 85 deg C – in order to accelerate wear and speed up the test. Each part was read every 100,000 cycles to see if it had failed, that is, if one or more bits were incorrect. We used PDIP packages, wrote in page mode, and operated at 5.5 volts.
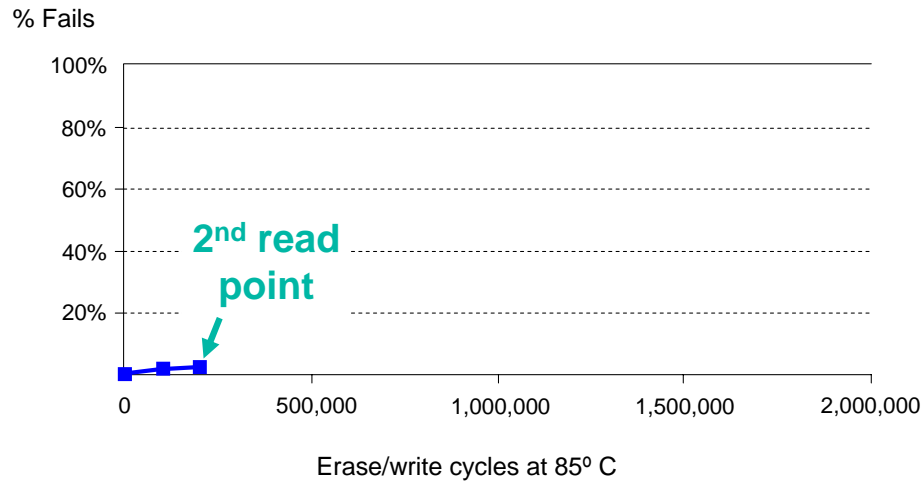
Notice that the empty graph now on the slide looks a lot like the Total Endurance™ graphical output. The major differences are 1) the y-axis here is in percent fails not ppm and 2) while the Total Endurance tool is a model, this data is based on actual cycling.
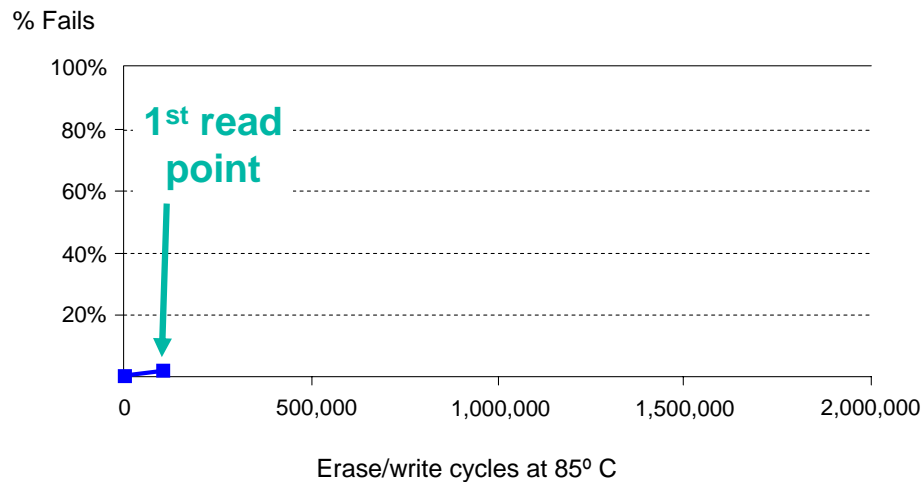
Here are the results from the first read point for supplier number 1. After only 100,000 cycles, there were already some failing parts.
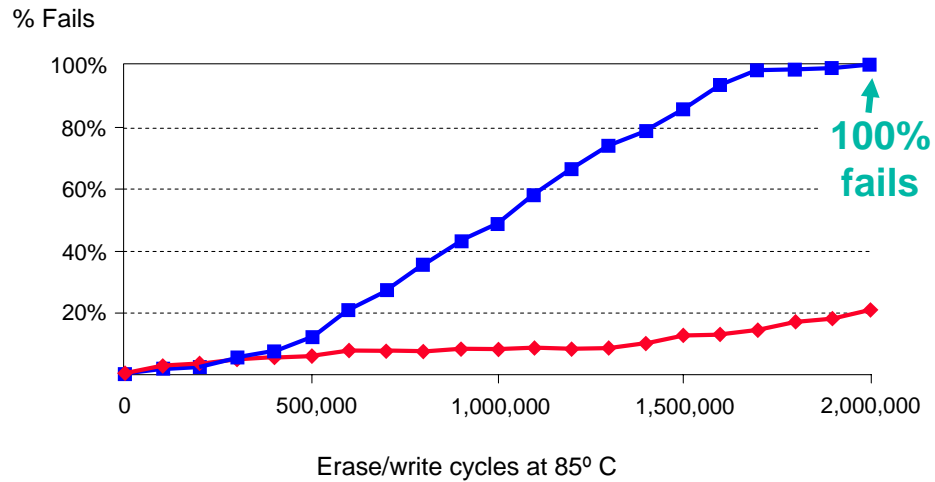
Endurance Test Results:
3 Manufacturers

% Fails

100%
80%
60%
40%
20%

2nd read point

0   500,000   1,000,000   1,500,000   2,000,000

Erase/write cycles at 85º C

<u>Now</u> I will add data from the 2nd read point, at 200,000 cycles. There are more fails, on the order of 2%, But, 2% means 20,000 ppm!
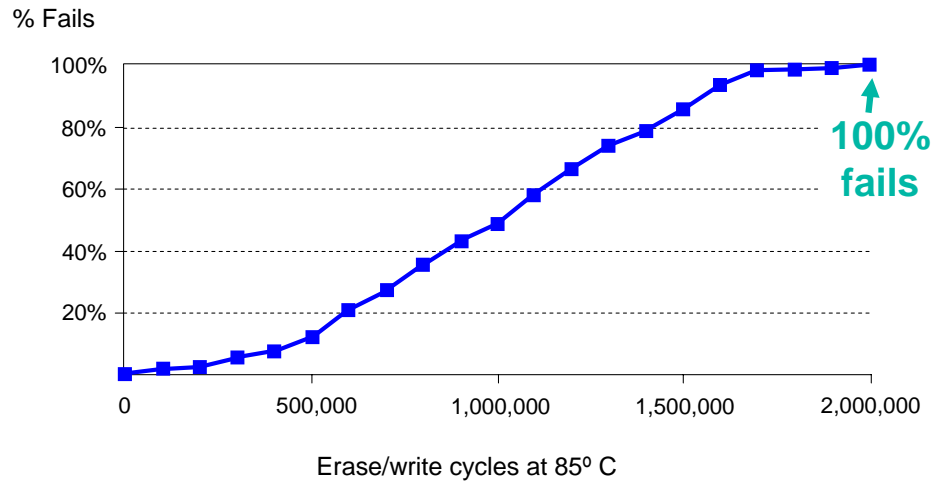
Here is the rest of the test data for the first supplier. By the end of the test, 100% of the 128 units that we tested failed. This is a very harsh test environment, well above the data sheet specification, but the results are not very impressive.

Endurance Test Results: 3 Manufacturers

This 2nd vendor had better results. Still, after the 2-million cycle test, 20% of the units had failed.

Endurance Test Results: 3 Manufacturers

% Fails

100% fails

Early fails

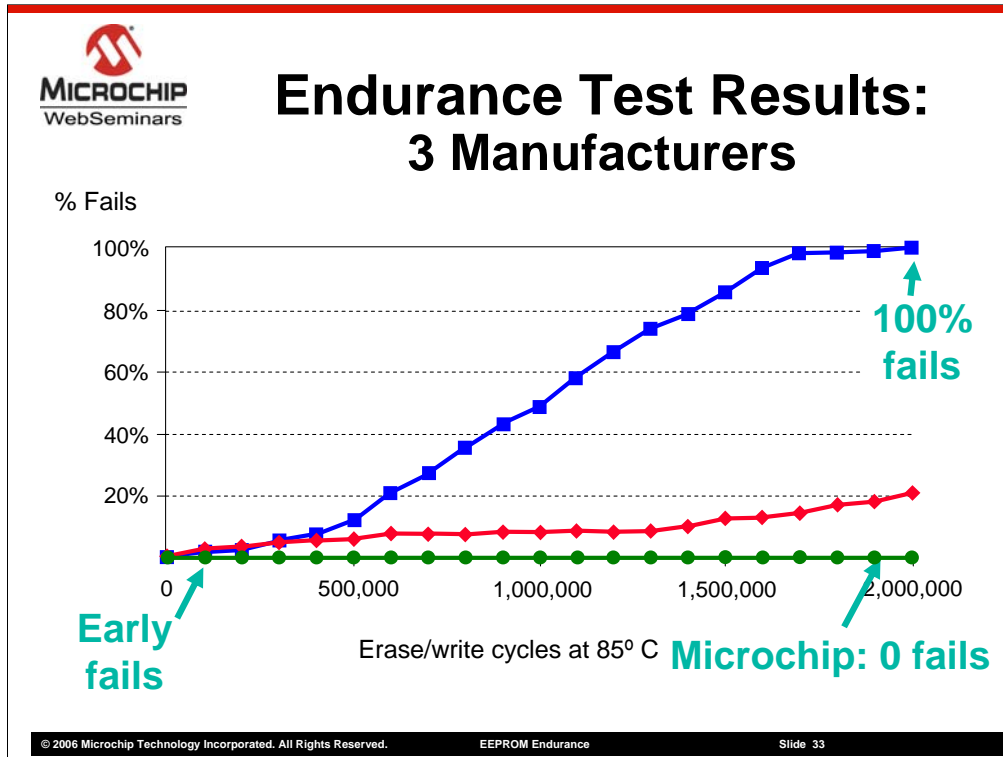Erase/write cycles at 85º C
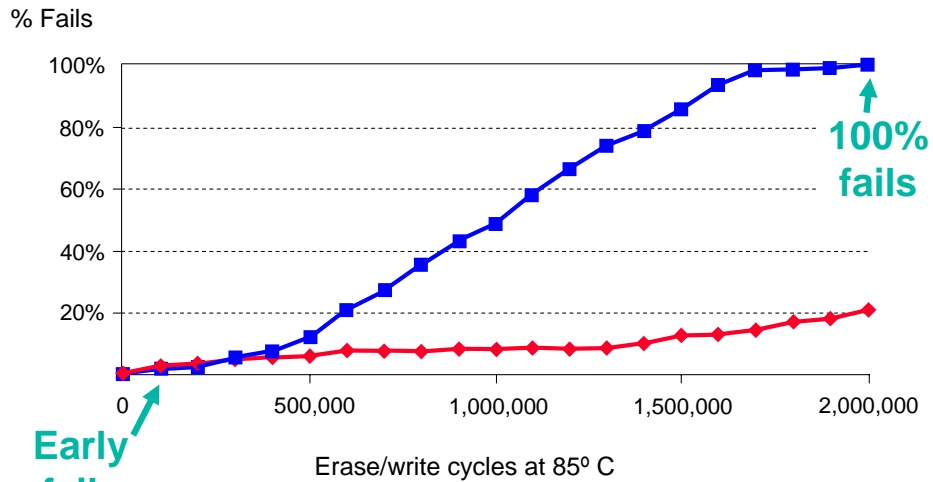
© 2006 Microchip Technology Incorporated. All Rights Reserved.   EEPROM Endurance   Slide 32

And, note that both these suppliers exhibited several _early fails_ before the first read point of 100,000 cycles. Eliminating these early fails is crucial, since most applications never reach millions of cycles.

Finally, I will add the Microchip results. Microchip devices showed no fails throughout the entire test. Now that the 3 curves are on the graph, you can really see the drastic differences in endurance results. We make the following 3 conclusions from this data:
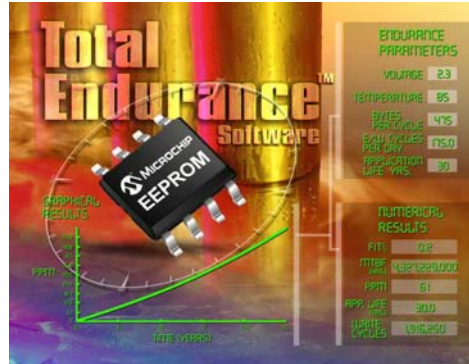
1. EEPROMS made by different manufacturers can have drastically different endurance characteristics
2. All these parts were specified to 1 million cycles. Data sheet definitions are not enough to make good decisions in harsh conditions.
3. This test emphasizes Microchip's reputation of having excellent endurance

To expand on that last point, we at Microchip are very proud of our endurance. We spend a lot of resources designing parts that will have excellent endurance, and we also use extensive testing to reduce early fails and ensure outgoing quality. Even if your application does not need millions of cycles, you can be assured that Microchip parts are built and tested to the highest quality.

EEPROM Endurance

- **Definitions and Education**
- **Ways to improve endurance**
- **Total Endurance™ software**
- **Endurance testing**

Thanks!

And that concludes this web seminar. Let's review the major topics we covered.

We had a quick review of endurance and defined some key terms, including a warning about how data sheet definitions can be incomplete.

Then we talked about the cell structure of EEPROMs and some ways that engineers can increase endurance in specific applications.

We completed an example case using our Total Endurance™ software, highlighting how quick and easy it is to make design decisions.

Finally, we just looked at some endurance data from different suppliers that emphasized the differences among products.

Our goal is to help you understand EEPROM endurance so you can make good design decisions. The centerpiece of that education is the Total Endurance software – the only model of its type in the industry.

Thanks very much for your time.